A SANITARY SURVEY OF LAKE ERIE, OPPOSITE CLEVELAND, OHIO, 1920[1]

By J. W. Ellms[2]

OBJECT AND SCOPE OF INVESTIGATION

In connection with the extensive studies made by the Division of Water for the purpose of preparing plans for the present and future expansion of the water works of Cleveland, it seemed desirable to undertake a sanitary survey of Lake Erie opposite the city and its suburbs. The principal object in view was to discover, if possible, areas of least pollution in which new intakes might be located. A secondary object was also in mind, namely, to procure a record of the extent and degree of pollution of the lake water resulting from the direct discharge of raw sewage into the lake, as is now the practice, and before the two sewage disposal plants now being constructed were placed in operation. After the latter have been started, it will be possible to make another survey and thus determine the effect of the disposal processes in diminishing the pollution of the lake water.

As a more intensive study of shore conditions, particularly with reference to the pollution of bathing beaches, and the water at the mouths of sewer outfalls, was also desired by the Division of Engineering, the Division of Water collected samples periodically from a large number of points near the shore which had been selected by the sub-division of sewage disposal of the Division of Engineering. These samples, together with others taken by collectors of this latter division, were examined in the laboratory of the sewage disposal division. There were approximately 1800 samples of water examined by the laboratories of the Water Department during this investigation. The results obtained are given in a condensed form as a part of this paper.

[1] Presented before the Cleveland Convention, June 7, 1921.

[2] Engineer of Water Purification, Water Department, Cleveland, Ohio.

WATER SUPPLY OF CLEVELAND

The water supply of Cleveland is drawn from Lake Erie through two intakes located about 3,700 feet apart. The Kirtland Street Pumping Station intake is N. 35° W. of the mouth of the Cuyahoga River and approximately 20,000 feet distant. The Division Avenue Pumping Station intake crib is N. 42° W. of the mouth of the river, and about 23,100 feet from the latter. The tunnels connecting these intakes with the shore pumping stations are both approximately 26,000 to 27,000 feet in length. The Kirtland Street intake consists of a steel crib rising above the surface of the water. The water enters the crib from 10 to 28 feet below the surface and 22 feet from the bottom. The Division Avenue intake consists of a submerged crib and hence has no superstructure. The crib opening is approximately 35 feet below the surface of the water.

PREVIOUS INVESTIGATIONS

In 1904–1905 an investigation of the water supply of the city was conducted by Mr. G. C. Whipple. His report covered the sanitary condition of the water supply and its probable future quality after the intercepting system of sewers should have been completed. In connection with this work, he noted the approximate position for a new intake, which latter has since been built and is now known as the Division Avenue Pumping Station intake. Comparison of certain results obtained by Mr. Whipple with some of those obtained by the writer are of interest in showing the changes in the lake water during the past 16 years. During this period the large intercepting sewer system has been practically completed, although no sewage disposal plants are as yet in operation.

In 1911–1912, Mr. Daniel D. Jackson made a report on the sanitary condition of the Cleveland water supply and the probable effect of changes in sewage disposal. Both Mr. Jackson's and Mr. Whipple's reports contain much valuable information, and many important deductions from the data which they obtained. The present investigation has been confined to determining in a general way the sanitary character of the lake water over an area of approximately 250 square miles opposite the city, without discussing specifically the quality of the lake water now supplied to the city. This latter phase of the problem is adequately covered in the writer's annual reports on the purification of the city's supply.

METHODS FOLLOWED IN PRESENT INVESTIGATION

By reference to map in figure 1 it will be seen that the lake in front of the city and its suburbs was divided off into a number of sections by eight parallel lines, which started at the shore and extended N. 18°–30', W. for a distance of 8 miles. These lines were spaced 4 miles apart, with the exception of the most westerly line which was 8 miles from the next line to the east. A second set of lines, which were approximately parallel with the shore line, was also laid off;

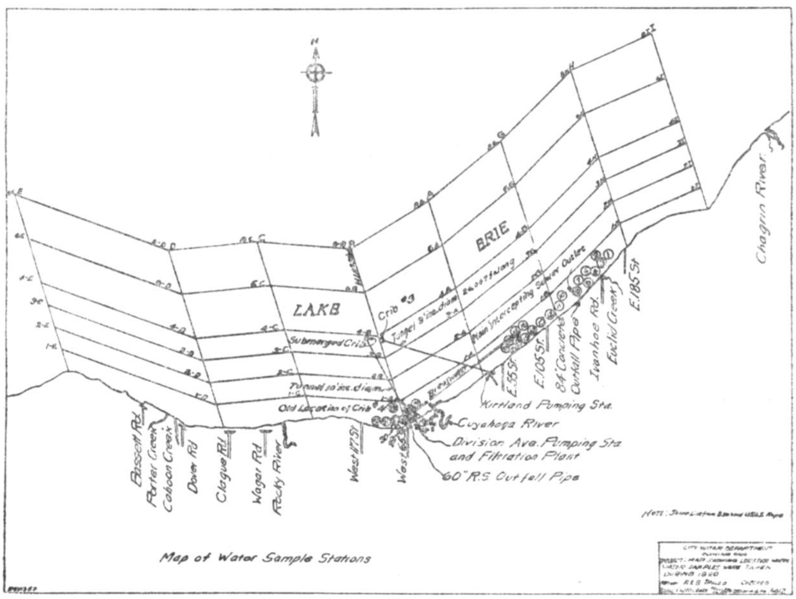

FIG. 1. MAP SHOWING SAMPLING POINTS IN LAKE ERIE

the first line being one mile from shore and the succeeding lines being 2, 3, 4, 6, and 8 miles, respectively, from the shore. At the intersection of the north and south, and east and west lines were located the sampling points used during this investigation. The north and south lines were lettered. The points formed by the intersection of the lines, which ran parallel with the shore, with those running north and south, were numbered. The numbers used were the same as the number of miles which the point was distant from the shore. By combining the range letter and number, as for example, Range B, Station 4, the exact location of the sampling point may be stated.

The ranges as lettered were located approximately as follows:

Range A—Nearly opposite the Kirtland Street Pumping Station.
Range B—Opposite foot of West 65th Street extended.
Range C—About $1\frac{1}{4}$ miles east of the mouth of Rocky River.
Range D—Nearly opposite Clague Road extended, and $2\frac{1}{2}$ miles west of Rocky River.
Range E—Nearly opposite Avon Point.
Range G—About $\frac{5}{8}$ mile east of East 105th Street.
Range H—Nearly opposite East 185th Street.
Range I—Opposite Maple Beach Hotel about 4 miles west of the mouth of Chagrin River.

The samples were collected from a motor driven launch 34 feet long, manned by three men, two of whom operated the launch, while the other man collected and labeled the samples. The samples were placed in an ice box on the launch immediately after being collected, and were transferred to a refrigerator in the laboratory as soon as the launch returned from the day's run.

There were first placed at the selected sampling points light wooden markers to assist the men on the launch in locating the stations. Each marker consisted of a cedar pole 10 feet long and 2 inches by 2 inches square. This latter was passed through the center of a 6 inch by 6 inch by 18 inch wooden float block, the pole extending about 5 feet on either side of the block. The marker was anchored by means of a $\frac{5}{8}$ inch rope fastened to a stone anchor. To make the marker easily visible, a triangular sheet iron flag painted red was attached to the top of the pole.

It was found after a while that several of the markers were missing, some of them disappearing more frequently than others. These latter lay usually in the path of the large vessels entering and leaving the harbor, and were probably run down and either dragged or disconnected from their anchors. In other cases the markers were apparently moved by wave action. As dependence evidently could not be placed upon the markers for locating the sampling points, resort was had to the use of land marks, the compass, and a taffrail log. Knowing the exact direction of all the range lines, and utilizing land marks for the starting point of these ranges, it was comparatively easy to fix the position of the intersections by using the taffrail log to determine the distance travelled by the boat along any given range.

One series of samples was collected in the latter part of the year, October 4, from a harbor tug, immediately following high winds, which had rendered the lake too rough to send out the launch. Even during the summer the sampling was interrupted more or less by stormy and foggy weather, which made it dangerous to venture out with the launch.

The greater number of samples were collected from the surface (1051), but 741 samples were collected from depths 10, 20, 30, and 40 feet below the surface. There were 143 chemical determinations made on certain samples, which were also used for bacterial tests. The first samples were collected on May 25, 1920, and the last October 7, 1920. As large a portion as possible of the total lake area being investigated was covered each day that sampling trips were made, but as a rule only about ½ the area was gone over daily, during which time 20 to 24 samples were collected.

It was decided before beginning this investigation, that the work should be confined almost entirely to bacterial examination of the water, as it was believed that these methods would throw the most light on the quality of the water and on the distribution of the sewage polluted water being discharged from the sewer outfalls and the Cuyahoga River.

"Standard Methods of Water Analysis" were followed in the bacterial work. The total number of bacteria grown on nutrient agar at 20°C. for 48 hours was determined in all cases. The differentiation tests for B. coli consisted in planting in lactose broth, thence to Endo's medium, and finally into lactose broth again for confirmation of gas formation which may have appeared in the first planting in lactose broth. Both in the plating on agar and for the isolation of B. coli types, different amounts of the sample were used where varying degrees of pollution were known or suspected. The bacterial results are expressed as the number present per cubic centimeter, where the total number is recorded, and as the number per hundred cubic centimeters, or the B. coli index, in the case of results of tests on this latter bacterial species.

So far as possible, constant observations of weather conditions were noted, particularly the velocity and direction of the wind. Knowing the great influence which wind movements have in producing and in varying the direction of lake currents, it was deemed advisable to record for any given period the prevailing direction of the wind and the average hourly velocity, as recorded by the instruments of the Weather Bureau at Cleveland.

COMPILATION OF DATA

The large amount of data obtained during this investigation has been compiled in various ways; but the charts and tables accompanying this paper summarize the results in such a manner that a comprehensive view of the entire investigation may be obtained. From the charts showing the average, median, maximum and minimum bacterial contours, there may be gained an insight of the fluctuations in the bacterial quality of the water, as well as, of its average and usual condition. The tables give the results in somewhat greater detail, although they are of necessity the final summation of a large number of individual results.

The comparison of the author's results with those obtained by Mr. G. C. Whipple in a similar investigation conducted by him in 1904, is of especial interest, and one from which some important deductions may be made. Mr. Whipple's original contour map has been reproduced in figure 7.

SOURCES OF POLLUTION

The pollution of the lake opposite Cleveland is derived chiefly from the City's own sewage. The outfall of the intercepting sewer on the west side of the city discharges directly into the lake at the foot of West 58th Street. On the east side of the city the interceptor discharges the collected sewage at East 140th Street. At various points along the shore of the lake stormwater overflows may at times also discharge diluted domestic sewage directly into the lake. Aside from these direct avenues through which pollution reaches the lake, sewage and trade wastes find their way into the water through the Cuyahoga River, Euclid Creek, Doane Brook, and Rocky River. There are several badly contaminated creeks that drain densely populated areas or manufacturing districts which empty into the Cuyahoga River. These streams are Big Creek, Burke Creek, Morgana Run, Kingsbury Run and Walworth Run. Probably a small amount of sewage reaches the lake through Rocky River, although Lakewood's sewage, with the exception of that which empties into Cleveland's sewer system. passes through a disposal plant, the effluent of which is carried directly to the lake through an outfall sewer. Some sewage much diluted and partially purified probably moves down the lake from Lorain, but it is not likely that it has any marked effect on the quality of the water opposite the city. The shore wash

of the whole area opposite the city and its suburbs must, of course, find its way directly into the lake and necessarily adds its quota of contaminating material to the lake water.

In addition to these sources of pollution there is also that derived from vessels navigating the lake. The opportunity for contamination of the lake water opposite the city by vessels is by no means negligible, especially if care is not used in discharging sewage from boats entering and leaving the harbor.

DISPERSION OF SEWAGE IN LAKE

The distribution of the sewage being discharged into the lake through sewers, creeks and the Cuyahoga River takes place along the whole water front opposite the city. It is, of course, immediately subjected to great dilution and, therefore, to the natural purifying agencies in the lake water. It is also fortunate that, so far as the rivers and creeks are concerned, they are for the greater part of the year merely lagoons of the lake with very low current velocities. The spring freshets as well as any sudden drop in the lake level will tend to increase these velocities, and thrust the pollution farther out into the lake. Any rise in the lake level will have a reverse effect. The movement of ice during the winter months acts like an immense stirring paddle and may carry pollution more directly to any given point.

The greatest factor in the dispersion of this polluted material, however, is the wind. Its velocity, duration and direction tend to set up currents in the water. Its effect is principally upon the surface, although undertow currents, particularly with on-shore winds, may cause contaminated water to be carried outward far beneath the surface. These effects are so pronounced and have been so well dealt with by previous investigators that further explanations are unnecessary.

DISCUSSION OF BACTERIAL DATA OBTAINED

Comparatively few samples were taken on Range E (table 1), which was 16 miles west of the mouth of the Cuyahoga River. One mile from the shore on this line, however, the bacteria averaged 3345 per cubic centimeter and decreased to 63 per cubic centimeter six miles from the shore. The maximum number found one mile

TABLE 1

Sanitary survey of Lake Erie opposite Cleveland, Ohio. Average, maximum, and minimum bacterial results

STATION NUMBER	SURFACE SAMPLES						10 FEET BELOW SURFACE						20 FEET BELOW SURFACE						30 FEET BELOW SURFACE						40 FEET BELOW SURFACE					
	Bacteria per cubic centimeter, agar 20°C.			B. coli per 100 cc.			Bacteria per cubic centimeter, agar 20°C.			B. coli per 100 cc.			Bacteria per cubic centimeter, agar 20°C.			B. coli per 100 cc.			Bacteria per cubic centimeter, agar 20°C.			B. coli per 100 cc.			Bacteria per cubic centimeter, agar 20°C.			B. coli per 100 cc.		
	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum
D-1	2,638	9,100	100	157	1,000	0																								
2	2,474	14,600	52	90	1,000	0																								
3	274	1,400	40	14	100	0	632	2,060	100	218	1,000	0	649	2,390	72	216	1,000	0	626	1,380	55	383	1,000	0	407	620	96	53	100	0
4	357	1,920	26	65	1,000	0	603	1,560	62	220	1,000	10	2,906	12,960	200	338	1,000	0	507	890	90	218	1,000	0	685	1,800	81	38	100	0
6	412	3,290	18	16	100	0	362	750	90	368	1,000	0	365	1,090	105	220	1,000	10	876	1,960	96	516	1,000	0	446	960	108	220	1,000	10
8	91	155	33	0	0	0																								
E-1	3,345	12,100	55	30	100	0																								
2	2,829	10,170	134	2.5	10	0																								
3	196	450	48	0.5	10	0																								
4	75	131	25	2	10	0																								
6	63	135	30	0	0	0																								
8	193	320	100	3.3	10	0																								
G-1	11,818	138,000	122	2,850	10,000	10																								
2	2,353	31,000	96	1,838	10,000	0																								
3	285	1,240	24	107	1,000	0	184	420	43	53	100	0	4,530	25,600	64	205	1,000	10	291	1,000	49	35	100	0	406	800	74	535	1,000	10
4	292	2,600	20	130	1,000	0	262	620	65	188	1,000	0	271	560	40	190	1,000	10	424	1,000	76	353	1,000	0	482	1,070	42	38	100	0
6	257	1,330	25	54	1,000	0	224	940	33	218	1,000	0	140	400	30	23	100	0	282	480	95	518	1,000	0	190	318	66	205	1,000	10
8	62	127	26	7	10	0																								

from the shore was 12,100 per cubic centimeter and decreased to 135 per cubic centimeter six miles from shore. Minimum numbers ranged from 25 to 134 per cubic centimeter, but these numbers were not always in an inverse ratio to the distance of the sampling points from shore. In fact, the 8 mile samples were higher than the 6 mile samples, indicating possibly the effect of shore pollution coming from a point still farther to the west. This is also true of the B. coli index, which, however, was quite low, never rising above 100 per 100 cc., and even averaging 0 per 100 cc. 6 miles from shore. No depth samples were collected on this range.

On Range D (table 1), which was 8 miles west of the mouth of the Cuyahoga River, the one mile station samples averaged 2638 bacteria per cubic centimeter, decreasing to 91 per cubic centimeter 8 miles from shore. The maximum number found was 2 miles from shore and averaged 14,600 bacteria per cubic centimeter, decreasing to 155 per cubic centimeter 8 miles from shore. The B. coli figures were quite low, ranging on an average from 157 to 0 per 100 cubic centimeter.

The depth samples collected at 10, 20, 30 and 40 feet below the surface averaged as high as 2906 bacteria per cubic centimeter at Station No. 4, with a corresponding maximum of 12,960 per cubic centimeter 20 feet below the surface, or higher figures than those obtained at depths of 10, 30 or 40 feet below the surface. The B. coli content averaged from 38 per 100 cc. to 516 per 100 cc., with maximums of 1000 and minimums of 0 per 100 cc., respectively. Depth samples were collected only at Stations 3, 4 and 6. Samples 4 miles from shore appear of somewhat higher bacterial content at all depths, than those at the other stations.

On Range C (table 2), which was 4 miles west of the mouth of the Cuyahoga River, the surface samples averaged 2,365 per cubic centimeter at one mile from the shore, decreasing to 42 per cubic centimeter 8 miles from shore. The maximum number was 14,200 per cubic centimeter, at Station No. 2, decreasing to 75 per cubic centimeter 8 miles from shore. The B. coli averages ranged from 590 per 100 cc. one mile from shore to 0 per 100 cc. 8 miles from shore, although maximums of 10,000 to 0 per 100 cc. were obtained at times at the different stations.

Depth samples did not differ greatly from those on Range D; in fact from inspection one would infer that they were somewhat lower, as a rule. Samples were collected at the various depths only at Stations 3, 4 and 6.

TABLE 2

Sanitary survey of Lake Erie opposite Cleveland, Ohio. Average, maximum, and minimum bacterial results

Station number	Surface samples						10 feet below surface						20 feet below surface						30 feet below surface						40 feet below surface					
	Bacteria per cubic centimeter, agar 20°C.			B. coli per 100 cc.			Bacteria per cubic centimeter, agar 20°C.			B. coli per 100 cc.			Bacteria per cubic centimeter, agar 20°C.			B. coli per 100 cc.			Bacteria per cubic centimeter, agar 20°C.			B. coli per 100 cc.			Bacteria per cubic centimeter, agar 20°C.			B. coli per 100 cc.		
	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum
A-1	7,623	112,000	600	4,375	10,000	100																								
2	5,677	81,000	126	2,040	10,000	0																								
3	326	1,270	17	183	1,000	0	390	2,100	63	329	1,000	10	378	1,640	88	400	1,000	0	413	1,820	67	313	1,000	10	519	2,510	88	213	1,000	0
4	231	1,460	6	53	1,000	0	179	510	20	223	1,000	0	282	780	36	295	1,000	0	401	1,890	28	304	1,000	0	301	1,220	36	303	1,000	0
6	267	3,750	20	77	1,000	0	272	140	18	104	1,000	0	325	1,400	48	116	1 000	0	765	3,730	55	310	1,000	0	364	1,170	53	220	1,000	0
8	69	220	6	1	10	0																								
B-1	12,814	117,000	203	2,692	10,000	10																								
2	3,670	31,400	65	915	10,000	0																								
3	525	3,220	29	139	1,000	0	232	500	92	317	1,000	0	176	530	54	174	1,000	0	226	550	33	275	1,000	10	177	410	75	304	1,000	0
4	303	830	32	110	1,000	0	183	380	95	54	100	0	165	490	55	151	1,000	0	816	3,250	38	289	1,000	0	905	4,220	28	290	1,000	0
6	355	1,990	40	77	1,000	0	161	350	35	267	1,000	0	373	970	38	51	1,000	0	428	1,960	15	401	1,000	0	228	720	72	189	1,000	0
8	107	184	15	2	10	0																								
C-1	2,365	12,700	160	590	10,000	0																								
2	2,198	14,200	37	26	100	0																								
3	327	1,360	10	420	10,000	0	168	350	61	161	1,000	0	399	1,520	32	45	100	0	339	1,490	37	190	1,000	10	488	1,570	96	487	1,000	0
4	365	2,240	31	160	1,000	0	217	350	38	201	1,000	0	369	1,170	20	431	1,000	0	433	1,660	138	343	1,000	0	415	1,300	100	460	1,000	10
6	223	1,240	26	57	1,000	0	281	460	106	428	1,000	0	287	660	90	315	1,000	0	480	1,810	45	201	1,000	0	2,359	15,500	97	58	100	0
8	42	75	18	0	0	0																								

On Range B (table 2), which was practically opposite the mouth of the Cuyahoga River, the surface samples averaged 12,814 per cubic centimeter, decreasing to 107 bacteria per cubic centimeter 8 miles from shore. Maximum counts ranged from 117,000 per cubic centimeter to 184 per cubic centimeter respectively, for these same stations. The B. coli figures averaged 2,692 per 100 cc. at one mile from shore and decreased to 2 per 100 cc. 8 miles from shore. The maximum and minimum B. coli indexes were 10,000 and 10, and 10 0 per 100 cc. respectively, at these same stations.

Depth samples which were collected only at 3, 4, and 6 miles from shore, show a somewhat greater number of B. coli, both average, maximum and minimum than do those on Range C, 4 miles farther west. This would be expected considering its position with reference to the Cuyahoga River.

On Range A (table 2), which was 4 miles east of the Cuyahoga River, the average number of bacteria at the surface showed quite a considerable decrease over those on Range B. The average number of bacteria found at Station No. 1 was 7,623 per cubic centimeter, decreasing to 69 per c.c. 8 miles from shore. The maximum number, however, was nearly as high (112,000 per cubic centimeter Station No. 1) as on Range A, and the minimum numbers were practically the same.

Depth samples 10 and 20 feet below the surface were somewhat higher in bacteria than those at 30 and 40 feet below the surface, although maximum and minimum figures do not differ greatly. The B. coli averages, maximums and minimums, do not vary greatly from those on Range B.

On Range G (table 1), 8 miles east of the Cuyahoga River and a little to the west of the outfall of the East 140th Street intercepting sewer, the effect of the latter is evident. The average number of bacteria at one mile from the shore was 11,818 per cubic centimeter, decreasing to 62 per cubic centimeter 8 miles from shore. The maximum range for those two stations was from 138,000 to 127 per cubic centimeter, respectively. These figures are similar, as might be expected, to those found on Range B nearly opposite the mouth of the Cuyahoga River.

The B. coli indexes averaged 2,850 and 7 per 100 cc., respectively, for 1 mile and 8 miles from shore, with maximums of 10,000 and 10, and minimums of 10 and 0 for these same stations.

The influence of the sewer discharge, which is carried out some distance under water, is clearly shown by the B. coli figures. At

20 feet depth an average B. coli index of 4530 per 100 cc. was obtained 3 miles from shore, and was as high as 140 per 100 cc. 6 miles from shore. The maximum indexes at these two stations and at 20 feet in depth were 25,600 and 400 B. coli per 100 cc., respectively. At 10, 30 and 40 feet in depth the figures are still quite high, and more particularly at the two latter depths.

On Range H (table 3), which is 4 miles east of Range G, and east of the East 140th Street sewer outfall, the bacterial content of the water was found to be still quite high. The average number one mile from shore was 4720 per cubic centimeter decreasing to 245 per cubic centimeter 8 miles from shore. A maximum number of 15,750 per cubic centimeter was found 1 mile from shore, although the number averaged 1100 per cubic centimeter 3 miles from shore, and 1940 per cubic centimeter 8 miles from shore. Here the general easterly movement of the lake water is in evidence.

Even the B. coli index averaged 3130 per 100 cc. at Station No. 1, decreasing to 22 per 100 cc. 8 miles from shore. Maximum and minimum indexes were 10,000 and 0, although 8 miles from shore an index of 100 per 100 cc. was found.

On the whole the depth samples showed rather high counts, especially so at the depth of 20 feet. At 6 miles from shore the average number of bacteria was 4406 per cubic centimeter with a maximum of 25,000 per cubic centimeter. Maximum and minimum B. coli indexes ranged from 1000 to 0 per 100 cc.

On Range I (table 3), which was 16 miles east of the mouth of the Cuyahoga River, and about 7 miles east of the East 140th Street sewer outfall, rather high counts were found on an average, and unusually high counts for depth samples. At one mile from shore the average number of bacteria was 4,914 per cubic centimeter with a maximum of 33,700 per cubic centimeter. At 8 miles from shore, the average number was 182 per c.c. with a maximum number of 1580 per cubic centimeter. Similar figures were obtained for the B. coli index. The average index at one mile from shore was 4,020 per 100 cc., with a maximum of 10,000 per 100 cc., and at 8 miles from shore the average was 35 per 100 cc., with a maximum of 100 per 100 cc.

The samples at all depths, and especially at 10, 30 and 40 feet, show rather high results, indicating the diffusion of the sewage being discharged at East 140th Street.

On figures 2, 3, 4 and 5 may be found contours of the bacterial content of the water based on the average, maximum, minimum and

TABLE 3

Sanitary survey of Lake Erie opposite Cleveland, Ohio. Average, maximum, and minimum bacterial results

STATION NUMBER	SURFACE SAMPLES						10 FEET BELOW SURFACE						20 FEET BELOW SURFACE						30 FEET BELOW SURFACE						40 FEET BELOW SURFACE					
	Bacteria per cubic centimeter, agar 20°C.			B. coli per 100 cc.			Bacteria per cubic centimeter, agar 20°C.			B. coli per 100 cc.			Bacteria per cubic centimeter, agar 20°C.			B. coli per 100 cc.			Bacteria per cubic centimeter, agar 20°C.			B. coli per 100 cc.			Bacteria per cubic centimeter, agar 20°C.			B. coli per 100 cc.		
	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum
H-1	4,720	15,750	72	3,130	10,000	0																								
2	2,034	10,400	68	1,041	10,000	0																								
3	299	1,100	17	133	1,000	0	276	1,000	62	53	100	0	289	560	36	250	1,000	100	473	1,060	77	383	1,000	0	395	1,130	47	188	1,000	0
4	303	2,460	23	94	1,000	0	133	237	55	203	1,000	0	339	840	53	353	1,000	0	364	1,120	62	38	100	0	700	3,130	126	535	1,000	10
6	279	1,480	16	19	100	0	670	1,340	169	55	100	10	4,406	25000	32	203	1,000	0	472	1,350	25	203	1,000	0	504	1,140	44	351	1,000	0
8	245	1,940	10	22	100	0																								
I-1	4,914	33,700	104	4,020	10,000	10																								
2	1,758	5,200	60	1,956	10,000	0																								
3	860	1,000	26	137	1,000	0	641	2,170	83	46	100	10	346	630	50	222	1,000	0	240	430	118	46	1,000	10	590	1,300	170	442	1,000	10
4	350	2,260	48	128	1,000	0	3,154	13,350	300	262	1,000	10	663	1630	95	442	1,000	10	6,913	25,000	112	262	1,000	10	3,234	15,000	178	442	1,000	10
6	447	2,710	26	161	1,000	0	546	1,280	100	28	100	10	682	1,890	170	82	100	10	571	1,440	230	442	1,000	10	579	890	174	24	100	0
8	182	1,580	20	35	100	0																								

median figures obtained at the various sampling stations. The necessary interpolations were made so that contours of even numbers could be drawn.

A study of these contours indicates very clearly the effect of the distribution of sewage pollution along the water front. From a point approximately a mile west of the mouth of the Cuyahoga River to a point east of the East 140th Street sewer outfall, the bacteria in the water average 10,000 to 12,000 per cubic centimeter, as far out as a mile from shore. This strip of water is the most polluted

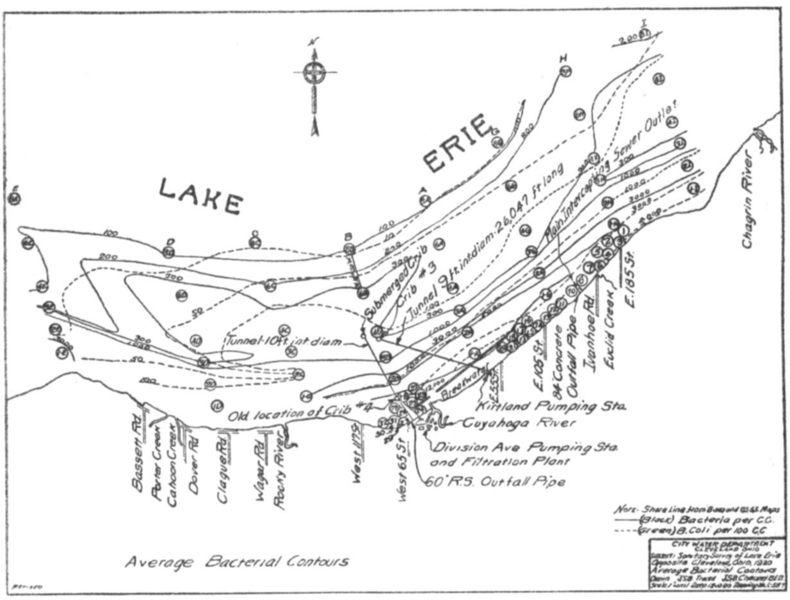

FIG. 2. AVERAGE BACTERIAL COUNTS AS CONTOURS

of any along the shore, as would be expected, since within it the Cuyahoga River and the two main sewer outfalls discharge the major part of the sewage and trade wastes of the city.

Running parallel with this contour is the 5000 bacteria per cubic centimeter contour about one mile farther out into the lake. At 3 miles from shore along this same section, the bacteria range from 1000 to 3000 per cubic centimeter. The 1000 per cubic centimeter contour appears to lie from 2½ to 3 miles from shore between Range E and Range I, or a distance of 32 miles paralleling the shore opposite the city and its suburbs. On this same contour map it will be noted

that there is a rather sudden drop in the bacterial content of the water 4 miles from shore. This is the 300 per cubic centimeter contour and is rather irregular west of the water works intakes, where it moves out to 5 and 6 miles from shore. To the east of the intakes, however, the line is within the 3 mile stations on Ranges A and G, but moves out to 4 miles on Range H and to 7 miles on Range I. This contour (300 bacteria per cubic centimeter) shows a rather curious approach toward the shore between Ranges D and E from about 7 miles to 3.5 miles. Between Ranges D and E this contour runs only 3 miles from shore. Evidently the diffusion of shore pollution is affected by the contour of the coast line at Avon Point. At 7 and 8 miles from shore the bacteria appear to average about 100 to 200 per cubic centimeter.

If we now consider the direct evidence of fecal pollution, as shown by the B. coli results, we find that the number of these bacteria range, on an average, from 3000 to 4000 per 100 cc. a mile from shore for a distance of 16 miles east of the West 58th Street. sewer outfall. The influence of the E. 140th St. sewer outfall is very marked. Along this same section the number falls to 1000 B. coli per 100 cc. about 2 miles from shore. It then drops rapidly to 100 B. coli per 100 cc. on the 4 mile off-shore line for this same section.

West of Range B, i.e., west of the mouth of the Cuyahoga River, the B. coli content of the water rapidly falls off, although the 1,000 B. coli per 100 cc. contour runs within a mile of the shore nearly to Rocky River. West of this, however, (Range C) the 50 and 100 per 100 cc. contours vary from 2 to 4 miles from shore. The 10 per 100 cc. B. coli contour approaches closely to Avon Point at the West, but is pushed out to the 6, 7, and 8 mile lines as it moves toward the east.

By reference to figures 3 and 4 the contours for the maximum and minimum bacterial content of the water may be seen. The wide variation from the average conditions is very apparent. For example, from Range B eastward to Range H and a mile off shore, the bacteria may go as high as 50,000 to 100,000 per cubic centimeter or from 5 to 10 times the average number present. They may drop as low as 100 to 200 or 300 for this same strip of water, which, as has been previously pointed out, receives the major part of the sewage and trade wastes of the city.

The maximum bacterial contours would indicate that the average number (10,000 to 12,000 per cubic centimeter) a mile from shore for this same strip of water may be pushed out to nearly 3 miles from

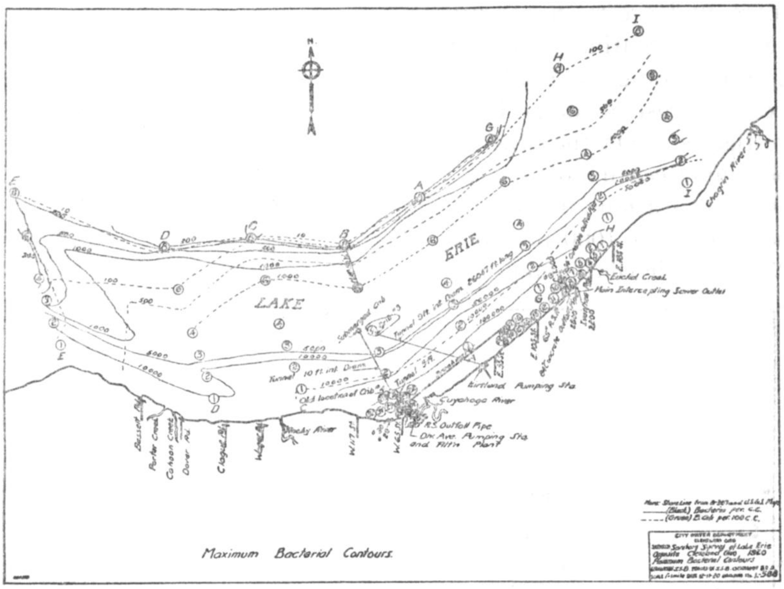

FIG. 3. MAXIMUM BACTERIAL COUNTS AS CONTOURS

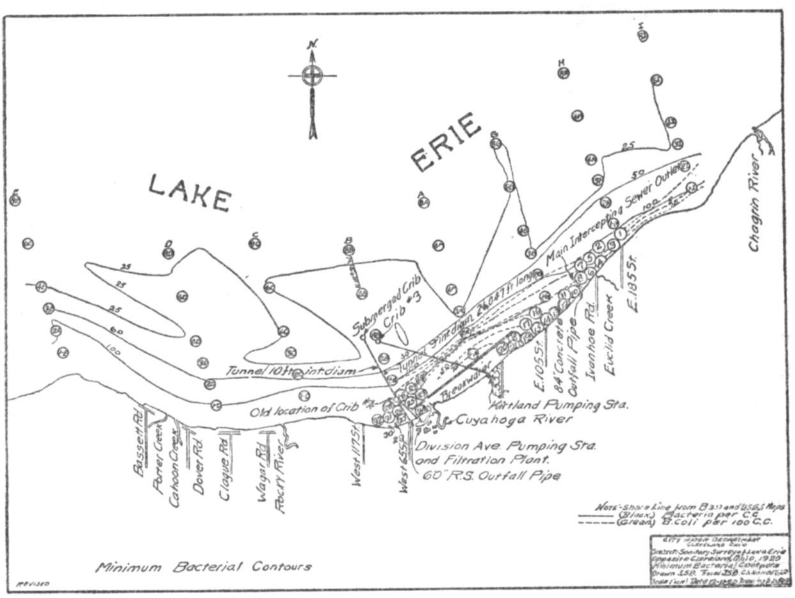

FIG. 4. MINIMUM BACTERIAL COUNTS AS CONTOURS

shore under certain conditions. Moreover, the 5000 and 10,000 per cubic centimeter bacterial contours for maximum conditions appear to range from 2.5 to 3 miles from shore from Range E at the extreme west to Range I at the extreme east portion of the area investigated. On the other hand the bacteria may drop as low as 50 per cubic centimeter on this same line. Even beyond the 6 mile off-shore stations the maximum bacterial content of the water may be as high as 1000 per cubic centimeter, and may drop as low as 25 per cubic centimeter.

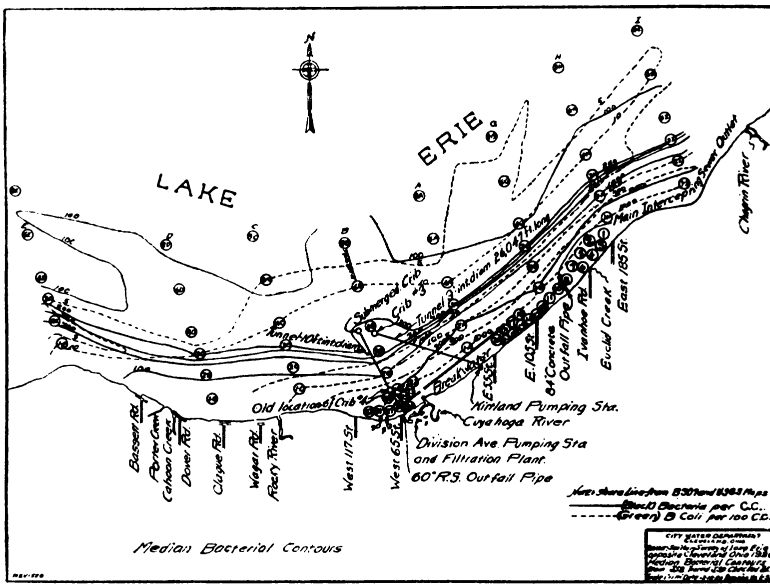

FIG. 5. MEDIAN BACTERIAL COUNTS AS CONTOURS

A study of the maximum and minimum B. coli shows the same wide variations from the average, and indicates clearly the potential danger of pollution due to lake conditions beyond human control.

On figure 5 which gives contours for median results, it is evident that under the usual summer and fall conditions, the bacterial content of the water may be expected to be 1000 to 2000 per cubic centimeter 2 miles from shore, dropping to 200 to 300 per cubic centimeter 3 miles from shore. At 4 or 5 miles from shore the water usually contains about 100 bacteria per cubic centimeter, although around the present water works intakes there are more frequently 200 to 300 bacteria per cubic centimeter.

The median B. coli content of the water a mile from shore between Range B and Range I is about 1000 per 100 cc. On the 2 mile off shore line for this same strip, the B. coli index falls to 100 per 100 cc., and at the 3-mile line it has fallen to 50 per 100 cc. Toward the west, however, the 5 and 10 per 100 cc. B. coli contours approach within 1.5 to 3 miles from the shore, and show the greater purity of the lake water under usual conditions.

On figure 7 there have been reproduced curves prepared by Mr. G. C. Whipple from the data which he secured in 1904. These contours do not cover as much area as was investigated by the writer, but they are interesting for comparing the same areas covered in both investigations. On Mr. Whipple's chart the contours do not extend west of Range D, 8 miles west of the mouth of the Cuyahoga River, nor farther east than Range A, 3 or 4 miles east of the mouth of the river.

In 1904, according to Mr. Whipple's contour chart, there were on an average 5000 bacteria per cubic centimeter in the lake water about 1.5 miles off-shore between West 117th Street and East 55th Street. In 1920, for this same section, the number of bacteria average about 10,000 per cubic centimeter. From 1.5 to 2.5 miles off-shore between Ranges D and A, the bacteria numbered about 1,000 per cubic centimeter in 1904, and about 5000 per cubic centimeter in 1920. At 3 miles from shore, the lake water averaged 500 bacteria per cubic centimeter in 1904, and 1000 per cubic centimeter in 1920. At 4 miles from shore, or near the present water works intakes, the bacteria averaged approximately 400 per cubic centimeter in 1904, and today will also average about the same number.

Comparing the turbidity of the water for the two investigations, as shown by Mr. Whipple's chart and the writer's (figure 6), it is evident that there is practically no difference. Near the shore the water usually has a turbidity of 30 to 50 p.p.m. diminishing to 15 or 20 p.p.m. 4 miles from shore.

Comparing the chlorides in the lake water during these two investigations, it is apparent that in 16 years the chlorine content of the water has practically doubled, or from 6.5 or 7.5 p.p.m. to 13 or 15 p.p.m. Taking into consideration that the population has almost doubled during this same period, this evidence of increased pollution may have considerable significance. The population of

the city and Cuyahoga County in 1904 and 1920, respectively, was as follows:

	1904	1920	Ratio
Population of city	445,000	796,836	1.80
Population of county	501,000	943,469	1.83
Population supplied with water	470,000	908,000	1.93

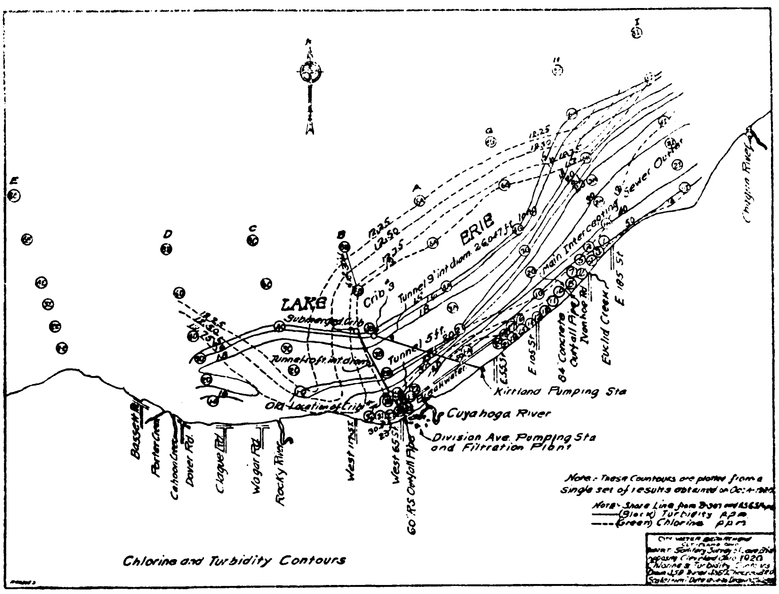

FIG. 6. TURBIDITY AND CHLORINE RESULTS AS CONTOURS

SUMMARY AND CONCLUSIONS

The increased pollution of the lake water along the whole water front during the past 16 years has been marked. The portion of the lake opposite the shore east of Rocky River and more especially the part east of West 117th Street is more polluted than the water to the west. This condition logically follows the denser population east of the mouth of Rocky River, and to the concentration of polluting material discharged into the lake from the outfall of the West 58th Street interceptor, from the Cuyahoga River with its contributing creeks within the city limits, from Doane Brook, from the East 140th Street sewer outfall and from Euclid Creek. The slow

general movement of the water along the shore toward the northeast appears to keep the polluted water near the shore, although diffusion is more pronounced the farther east the water moves, and becomes especially noticeable nearly opposite the mouth of the Chagrin River.

The quality of the lake water west of the water works intakes is notably better than to the east of them. However, it is rather curious that the 4 to 5 mile zone both east and west of the intakes is of

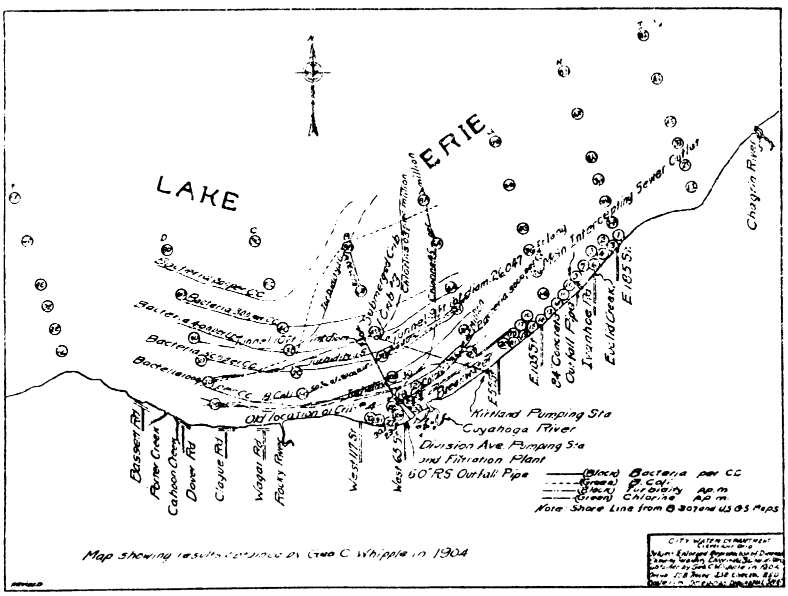

FIG. 7. REPRODUCTION OF TURBIDITY, CHLORINE, AND BACTERIAL RESULTS AS CONTOURS, PREPARED BY G. C. WHIPPLE IN 1904

fairly uniform good quality, on an average, for the 32 miles of shore water examined. This is not true, on the other hand, for conditions favoring maximum pollution, as evidenced by the bacterial figures on figure 3. It is the possibility of the latter conditions existing which should be taken into account in the location of new cribs. Viewed from this angle it will be seen, that the lake water may contain as many as from 1000 to 3000 bacteria per cubic centimeter in this zone, and that the B. coli may show an index of 500 to 1000 per 100 cc. The average and median figures for this zone (4 to

5 miles from shore) are well within those stated by the International Joint Commission on the Pollution of Boundary Waters as permissible, that is, the average number of bacteria which an efficient filter plant can safely handle.

The locations of the present intakes were wisely chosen. Unless efficient methods of sewage disposal, however, are put in operation within the next few years, these intakes will soon become engulfed in the general pollution gradually pushing its way farther and farther out from the shore. Already conditions producing maximum pollution of the lake water not infrequently submerge these intakes with badly polluted water and render the water supply correspondingly dangerous.

From the special series of samples taken on October 4, after a high wind had lashed the lake for several days into a very turbulent condition, it would appear that the mixing action brought about by high winds is on the whole beneficial. The polluted water is rapidly diffused through a large volume of water and greatly diluted. Natural agencies for purification are doubtless more active, although the water may be somewhat more turbid. It is not impossible, of course, that, depending on the velocity and duration of the wind, there might be at first a sudden and bad pollution of the water near the intakes. Our evidence, is not sufficient to prove or disprove this possibility but it is enough, it would seem, to show the extraordinary mixing action produced by high winds, and the consequent diminution in the average pollution.

The effect of the wind in producing surface currents is well understood, and accounts for the wide and erratic fluctuations in the bacterial content of the lake water. The duration, velocity and direction of the wind are, of course, of the greatest importance. Nevertheless, the extraordinary difficulty of trying to coördinate any particular set of conditions with the quality of the water at any point, necessitates only the most general of statements. Mr. G. C. Whipple showed for the year 1904 that the off-shore winds only slightly exceeded the on-shore winds. During the fall (September to January) the total wind movement off-shore slightly exceeded the on-shore winds, while for the remaining 7 months the on-shore winds exceeded the off-shore winds.

During this investigation, it would appear that the prevailing winds were from the north-east, north-west and south-west. In general, the wind blowing down the lake exceeds the movement up

the lake, as Mr. Whipple pointed out in 1904. This tendency probably accounts for the polluted water moving usually to the east along the shore, quite as much as the effect produced by the slow general movement of the whole body of water down the lake toward Lake Ontario.

The conclusions reached as to the location of new water works intakes are as follows:

1. The average quality of the water in the 4 to 5 mile zone for any location along the entire 32 miles investigated is suitable for water supply purposes, if properly purified before distribution. In other words, water from this zone will not unduly burden a well operated filtration plant.

2. The water is better west of Range B than east of it, and intakes for the west side of the city might possibly be located within the 3.5 and 4.5 mile zone.

3. The water east of Range B should not be taken less than 4 miles from shore, and preferably as far toward the west as possible.

It is hoped that with the installation and operation of the sewage disposal plants now under construction and proposed by the city, that the pollution of the lake will diminish to a greater or less extent. If this effect is produced, the line of gross pollution will not continue to advance into the lake even though the population shall continue to increase. Against sudden pollution of intake waters, there is no remedy except purification of the water supply. To keep down lake pollution resort must be had to efficient methods of sewage disposal.